16. MINERALOGICAL AND GEOCHEMICAL INVESTIGATIONS OF SEDIMENTS ON THE MAZAGAN PLATEAU, NORTHWESTERN AFRICAN MARGIN (LEG 79, DEEP SEA DRILLING PROJECT)[1]

Hervé Chamley and Pierre Debrabant, Université de Lille I [2]

ABSTRACT

Detailed mineralogical and geochemical studies were performed on samples from selected time intervals recovered during Leg 79 on the Mazagan Plateau. The uppermost Albian and Cenomanian sediments of Sites 545 and 547 can be correlated on the basis of mineralogy and geochemistry; these sediments illustrate differential settling processes and the existence of hot climates with alternating humid and dry seasons in the African coastal zone. The upper Aptian to Albian black shales of Site 545 point to an irregular alternation of tectonic activity and relaxation stages, allowing different behaviors in the reworking of soils, crystalline rocks, and sediments born in peri-marine basins. The barren lower Mesozoic reddish sediments and evaporitic series of Sites 546 and 547 are characterized by a strong physical erosion of sialic landscapes, without clear evidence of post-depositional metamorphic events. At Site 546 strong early diagenetic processes in a confined evaporitic environment affect both the mineralogy and the geochemistry of pre-Miocene rocks.

INTRODUCTION

Mineralogical and geochemical investigations have been made on selected lithofacies representing specific time intervals, from sedimentary materials of Sites 545, 546, and 547 of the Deep Sea Drilling Project Leg 79, on the slope of the Mazagan Plateau, off Morocco. The Mesozoic carbonate platform in this area is structurally controlled by either diapiric structures or sialic basement (Fig. 1) (site chapters, this volume). The aim of the study was to obtain information on the stratigraphy, paleoenvironment, and diagenetic evolution of the sediments. Detailed studies have been made on the upper Albian to Cenomanian green nannofossil claystone recovered at Sites 545 and 547 and on the lower Mesozoic red clays, halite, and associated facies encountered in cores from Sites 546 and 547. We also have investigated samples of upper Aptian to Albian sediments from Site 545, and Cenozoic clayey to calcareous oozes from Site 547. Table 1 summarizes the sites studied.

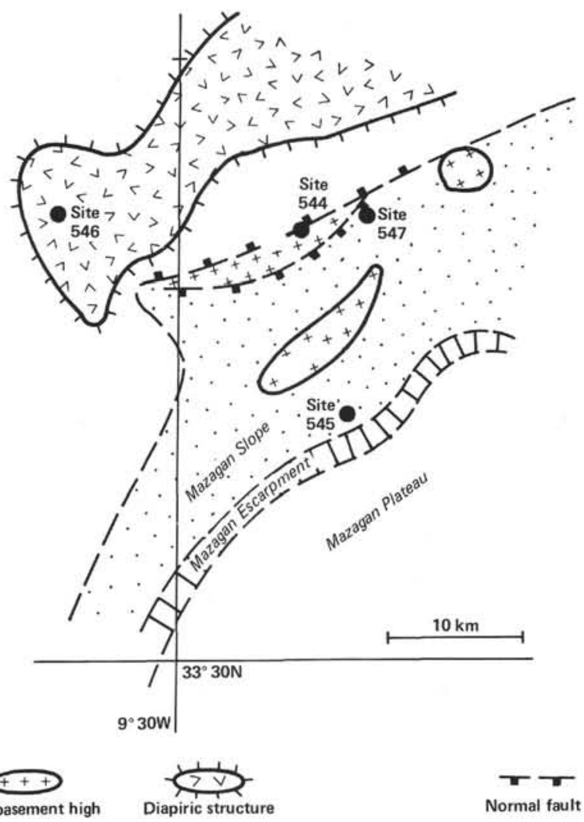

Figure 1. Location of Leg 79 sites.

ANALYTICAL PROCEDURES

The X-ray diffraction method was as follows. The samples were dissociated in water, then calcium carbonate was removed in 5*N* hydrochloric acid. Excess acid was removed by successive centrifuging; deflocculation was improved using a microhomogenizer. The fraction smaller than 2 μm was collected by decantation, following settling times determined by using Stokes' law; then oriented pastes were made on glass slides. A Philips Model 1730 diffractometer (copper radiation) was used to make the X-ray diffraction scans at 2°2 Θ/min. Three diffractograms were made (1) from 2.5° to 28.5°Θ on natural samples; (2) from 2.5° to 14.5° Θ on glycolated samples; (3) from 2.5° to 14.5° 2Θ on samples heated for 2 hours at 490°C. The quantitative evaluations obtained are based on peak heights and areas (Chamley, 1979). The heights of illite and chlorite 001 peaks (diagram for glycolated sample) were taken as references. By comparison with these values, values for smectite, palygorskite, sepiolite, vermiculite, and irregular mixed-layer clays were corrected by addition of peak height (× 1.5-2.0 according to the crystallinity of each species), whereas values for well-crystallized kaolinite were corrected by subtraction (× 0.7-0.5, depending on kaolinite crystallinity). The relative proportions of chlorite and kaolinite were determined from the ratio of the heights of the 3.54 and 3.57°Å peaks, respectively. When this ratio is 1, the amount of chlorite is assumed to be twice that of kaolinite. Data are given in percentages, the relative error is estimated at ±5%. Additional data concern the bulk mineralogy obtained by X-ray diffraction on randomly oriented powders.

[1] Hinz, K., Winterer, E. L., et al., *Init. Repts. DSDP*, 79: Washington (U.S. Govt. Printing Office).

[2] Address: Sédimentologie et Géochemie. ERA 764 CNRS, Université de Lille I, 59655 Villeneuve d'Ascq, France.

Table 1. Site summaries.

Site	Location	Water depth (m)	Penetration (m)	Nature of bottom sampled	Age and number of samples
544	33°46.00′N 09°24.26′W	3607	235	Gneiss	early Mesozoic 3
545	33°39.86′N 09°21.88′W	3150	701	Dolomite	late Aptian to Cenomanian 25
546	33°46.07′N 09°33.09′W	3992	129	Halite	early Mesozoic 27
547	33°46.08′N 09°21.00′W	3940.5	1030	Mudstone	Pliocene, Paleocene 6 Albo-Cenomanian 39 early Mesozoic 14

Electron-microscopy observations were made with a Siemens transmission microscope, on less than 8 μm particles deposited on copper grids covered by a collodion film after carbonate removal and physical deflocculation.

The geochemical procedure was the following: The samples were dried at 105°C, crushed, and homogenized. Then 0.2 g was subjected to alkaline fusion, solubilized by HCl, diluted to 100 ml, and treated fluoronitrically in a bomb at 150°C and 50 bars for SiO_2 and Al_2O_3 determination. Also, 1 g was subjected to fluoroperchloric treatment, solubilized by HCl, and diluted to 100 ml. The dilutions were used for colorimetric analysis of TiO_2 and P_2O_5 and for spectrophotometric determination of other major and trace elements by atomic absorption analysis, using a Type 5000 Perkin Elmer automated spectrophotometer. The reproductibility of the measurements is ±3% for major elements, ±10% for trace elements.

LATE CRETACEOUS TO EARLIEST PALEOCENE

The Upper Cretaceous to lowest Paleocene claystones to marlstones of Hole 547A (Cores 32A–38A) are marked by abundant smectite (80%) accompanied by palygorskite (10%), illite (5%), and little amounts of sepiolite, chlority, and irregular mixed layers. Such an assemblage is well known during this period, especially in the earliest Paleogene of The northeastern Atlantic, and is considered as reflecting hot and humidity-contrasted climate on adjacent landmasses (Mélières, 1978; Chamley, 1979).

LATE ALBIAN AND CENOMANIAN, SITES 545 AND 547

Upper Albian to Cenomanian deposits of Site 547 consist of nannofossil claystone to mudstone with intraformational clay pebble structures and slump structures (Cores 547B-5 to 547B-2, 547A-73 to 547A-39, 350 m thickness), while those of Site 545 consist of green nannofossil claystone with some slump structures (approximately Cores 545-40 to 545-29, 124 m thickness (Fig. 2). In spite of these differences, the clay mineralogy and bulk geochemistry are fairly similar at both sites. Smectite is very abundant (50–90% of clay minerals) and is associated with kaolinite (5–25%), palygorskite (traces to rarely 45%), illite (traces to 10%), chlorite and irregular mixed-layer clays (traces), quartz (common), and opal-CT (rare) (Plate 1, Figs. 1–4). These mineralogical similarities suggest a comparable origin for the different species in both sites. A predominantly detrital origin for the clay assemblages is interpreted based on previous studies on the Moroccan margin and in the whole North Atlantic Basin (Mélières, 1978); Chamley, 1979; CEPM, 1980; Chamley et al., 1980) and also is supported by the extent of resedimentation structures, high sedimentation rates, and absence of correlation between detailed lithology and clay mineralogy. The abundance of Al-Fe smectites and kaolinite indicates the probable importance of pedogenic processes on the landmasses and the existence of hot climates with alternating wet and dry seasons (Chamley, 1979). The data from Leg 79 agree well with those from Legs 41, 47, 48, and 50 from the eastern North Atlantic.

The inorganic geochemistry changes moderately with depth in the sedimentary column, and the variations observed depend chiefly on the variations of the $CaCO_3$ content (13–65%). Metalliferous accumulations do not occur (Figs. 3, 4): the detrital character of the sedimentation (parameter D) dominates everywhere; the absence of manganese precipitation (parameter Mn*) indicates a reduced environment and a high sedimentation rate (Debrabant and Foulon, 1979). The aluminoferrous characteristic of geochemical parameters results from the presence in noticeable amounts of smectite (Fe) and kaolinite (Al).

In spite of this general homogeneity, minor but significant mineralogical and geochemical changes occur with depth in the sedimentary column and permit stratigraphic correlations between Sites 547 and 545 (Fig. 2, Table 2).

The most important break occurs in the latest Albian, close to the Albian/Cenomanian boundary (Cores 547A-66 to 547A-64; Cores 545-38 to 545-37). It corresponds to a significant decrease of illite, palygorskite, potassium, magnesium, and phosphorus and a correlative increase of smectite, kaolinite, aluminum, and iron (Fig. 2 and 5; see also Table 3). The good correlation existing in both Sites 547 and 545 for the late Albian and latest Albian-Cenomanian time intervals is clearly summarized in Figure 3, which shows the respective abundances of Al_2O_3 and MgO. Additional differences between both time intervals can be observed in Sites 545 and 547 (Figs. 3 and 4), namely a decrease of CaO and an increase of 10^3 Sr/CaO at the late Albian/latest Albian boundary, which probably indicate a selective dissolution of calcite in a reducing diagenetic environment (Maillot and Robert, 1980) and the transfer of strontium from carbonates to smectites.

The general inorganic stratigraphy reported here could be useful in order to support the biostratigraphical scale in a depositional environment characterized by noticeable dissolution processes and by sedimentary reworking.

Significant lateral changes also occur if comparing the clay mineralogy of Sites 547 and 545 (Fig. 2).

	Site 545	Site 547
Illite	tr–10%	tr–5%
Smectite	60–75%	65–90%
Kaolinite	15–25%	10–20%
Palygorskite	tr–10% (maximum 45%)	tr–5% (maximum 35%)

Smectite is more abundant at Site 547. As deduced from previous studies (Millot, 1964; Chamley, 1979), smectite appears to originate chiefly from the reworking of coastal soils and surficial coastal sediments, while other

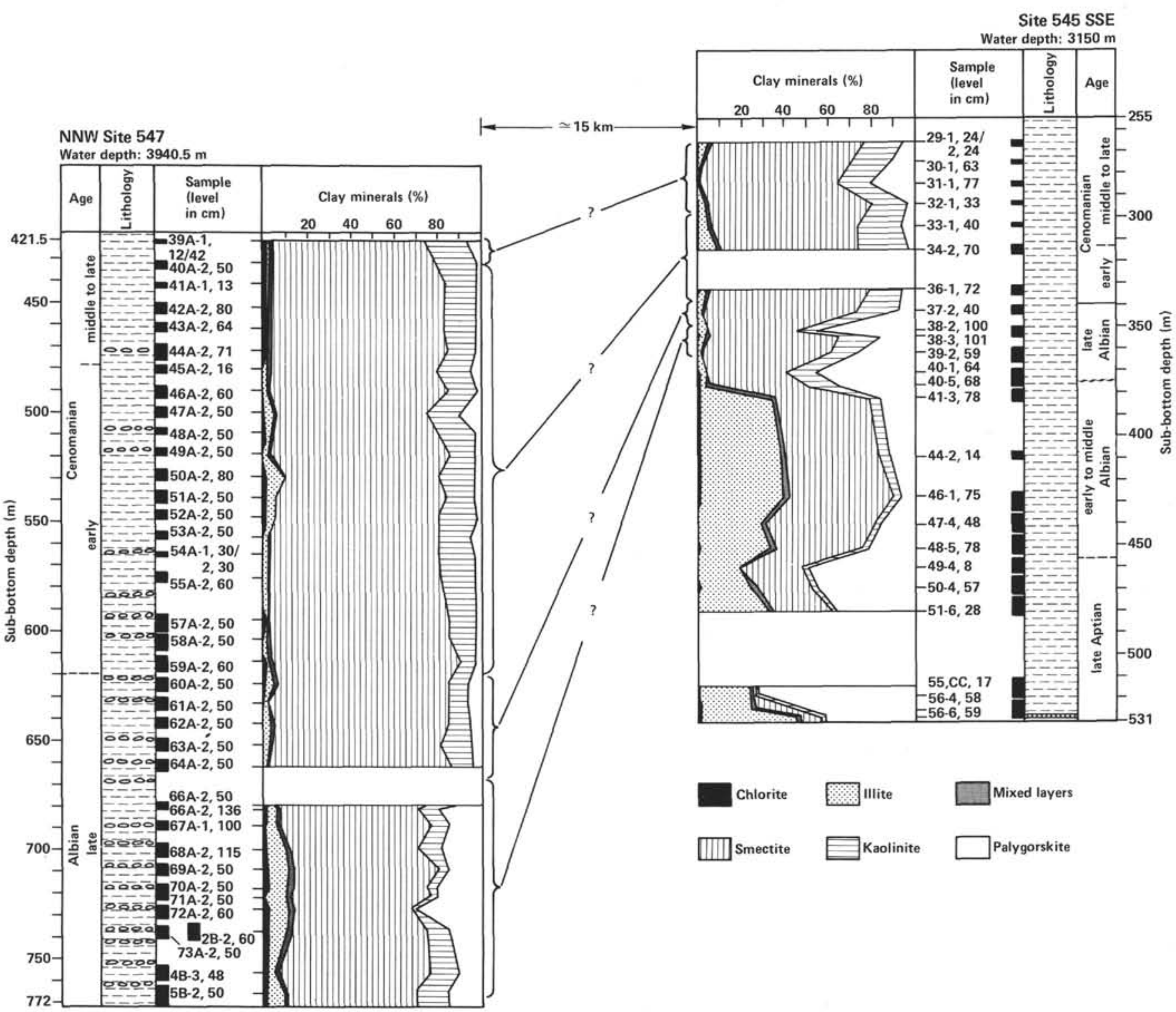

Figure 2. Cretaceous clay stratigraphy and tentative mineralogical correlations, Sites 545 and 547. A and B indicate Holes 547A and 547B. For updated biostratigraphic correlations see chapters by Leckie (this volume) and Wiegand (this volume).

minerals are mainly reworked from various rocks (illite, palygorskite) and upstream soils (kaolinite). Smectite is well known in modern marine environments for its ability to settle later than other minerals, especially illite and kaolinite (Whitehouse et al., 1960; Gibbs, 1977). Thus, it is suggested that during the mid Cretaceous differential settling processes occurred off the northwestern African margin. These processes determined the preferential sedimentation of illite and associated minerals at Site 545, which is located at the foot of the Mazagan Escarpment, and the preferential sedimentation of smectite at Site 547 located more distally. The parallel mineralogical variations recorded at both sites indicate a more proximal situation for Site 545 favoring supply from rock and soil products, a more distal situation for Site 547, favoring supplies from soil products downstream.

LATE APTIAN TO MIDDLE ALBIAN, SITE 545

The lower part of Site 545 Cretaceous green nannofossil claystones (Unit III) represents the late Aptian to middle Albian (Cores 545-56 to 545-41 approximately). This sequence is characterized by slump structures, microfaults, and low-angle slide surfaces, pointing to resedimentation processes (site chapter, this volume). Illite, smectite, and palygorskite are the three major clay minerals, the relative proportions of each increase or decrease independently of the lithology or the depth of burial. Three major palygorskite peaks are apparent, marked by abundant bundles of well-preserved fibers in the sediments (Plate 2, Figs. 1, 2) and by high MgO/Al_2O_3 ratios. In some intervals the three clay minerals are present in comparable abundances (Plate 1, Figs. 5,

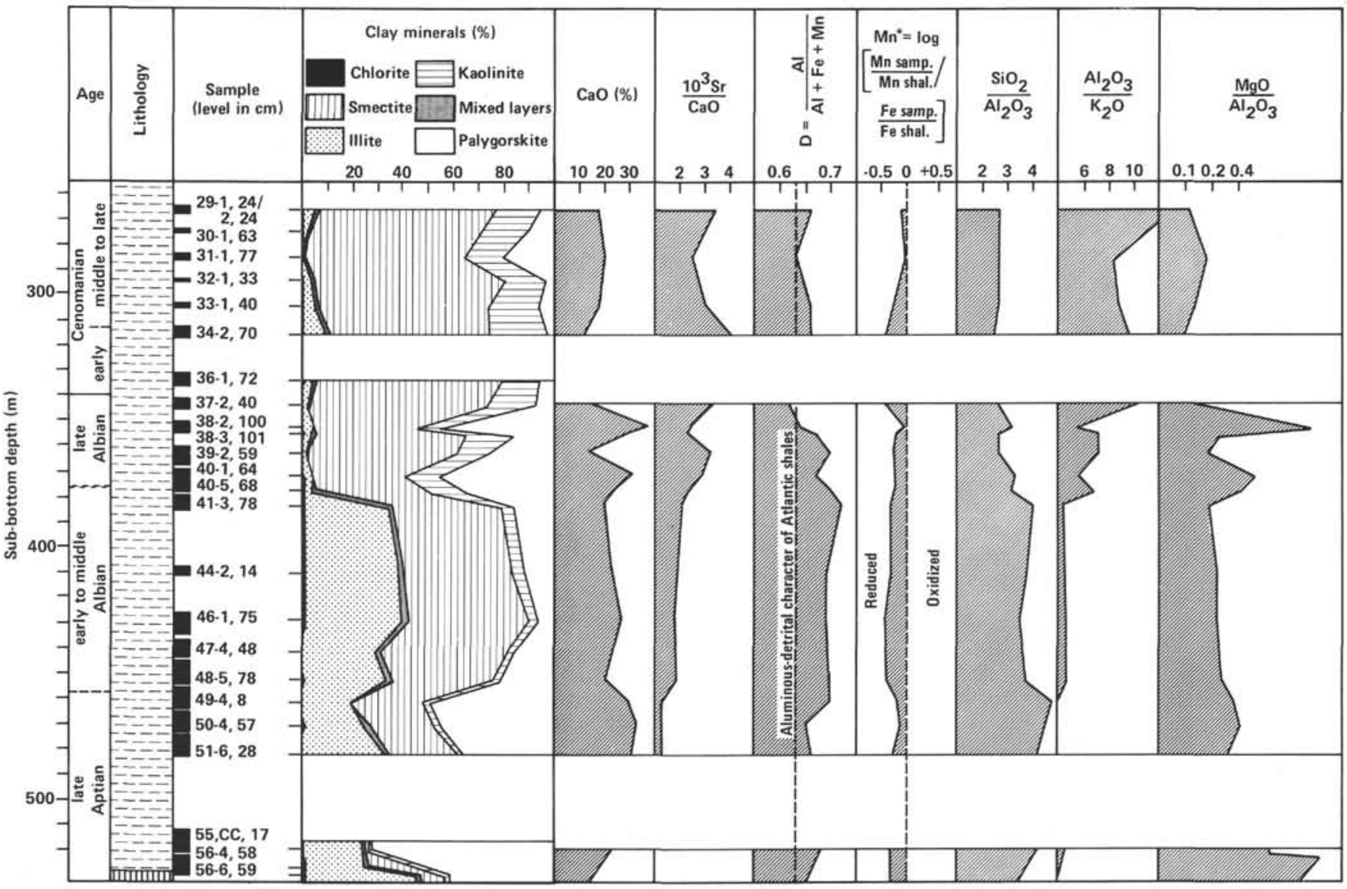

Figure 3. Cretaceous clay mineralogy and bulk geochemistry, Site 545.

6). Illite-rich levels correspond to low Al_2O_3/K_2O ratios. A strongly reduced character (Index Mn* < 0) occurs in the deposition environment, as well as a highly aluminous-detrital influence (D close to 0.7, Fig. 3). Slight phosphate concentrations appear at Sample 545-56-6, 59 cm (also magnesian rich and strontium poor) and Sample 545-44-3, 78 cm, suggesting temporary lower sedimentation rates. Occasional tectonic activity along the Moroccan continental margin during this time period may be responsible for higher sedimentation rates and the combined reworking of continental soils (smectite), or continental rocks especially from peri-marine basins (palygorskite), and of various marine sediments (i.e., Chamley, 1979). A major break occurs in Core 545-40: the decrease of illite and potassium, the increase of aluminoferrous smectites, and the presence of phosphates suggest lower sedimentation rates, the reworking of surficial continental formations (especially soils), and a tectonic relaxation during the late Albian and Cenomanian.

EARLY MESOZOIC, SITES 546 AND 547

Sediments of latest Triassic to earliest Jurassic age have been collected at Sites 546 and 547 (Figs. 6, 7). At Site 546 we have studied grayish red gypsiferous sandy clays (Cores 546-17 and 546-18, 149–156.5 m) where Miocene microfossils are mixed with Mesozoic elements, as well as halite banded with grayish red to grayish green and gray clayey streaks (Cores 546-18 and 546-20, 156.5–192 m). In Hole 547B we have considered the grayish red sandy mudstones, locally interbedded with dark gray sandy mudstones (Cores 547B-25 to 547B-34, 924–1030 m).

Sites 546 and 547 are characterized by the abundance of chlorite and illite in the clay fraction, with these being the only clay minerals in most sedimentary levels (Plate 2B, Figs. 3, 4). Quartz is ubiquitous. Dolomite, gypsum, and halite are frequent and are associated with relatively high amounts of MgO and frequently with Na_2O or $K_{20.}$ Lithium is the most typical trace element and probably accompanies the micaceous minerals. The presence of a sialic basement very close to the bottom of Hole 547B suggests the possibility of strong erosional processes acting on a poorly weathered continental crust. Traces of irregular mixed-layer clays occur locally only: Samples 546-20, 141 cm; 547B-34-2, 110 cm; and 33-3, 0 cm. The rareness of chemical alteration products could be due to the importance of physical alteration effects on a high-relief continental area at the time of deposition. Another cause of the peculiar clay mineralogy observed could be the occurrence of epimetamorphic events after sediment deposition, as it has been shown in the Permo-Triassic of northern Morocco (Robillard and Piqué, 1981). But there is no lithologic or petrographic evidence of any metamorphic influences off the Moroccan margin, an area located far away from the tectoni-

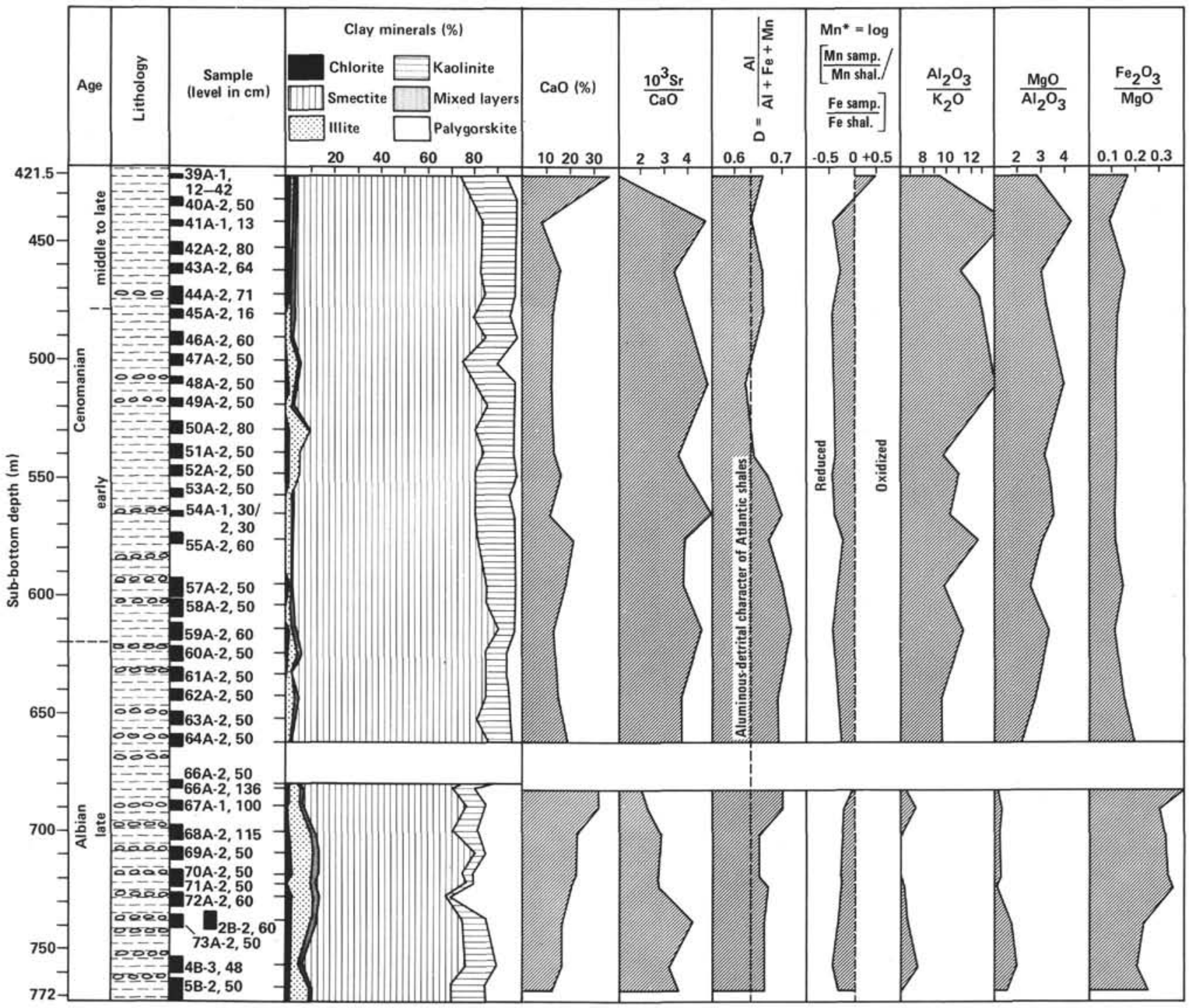

Figure 4. Cretaceous clay mineralogy and bulk geochemistry, Site 547.

cally active Atlas Mountains. Moreover, some mineralogical and geochemical differences do exist between Site 546 and Hole 547, and vertically oriented changes occur above the salt at Site 546 and not in Hole 547B. These data cannot be easily explained in an epimetamophic context (see later). Thus, we do prefer the hypothesis of a strong mechanical erosion of sloped continental relieves.

In spite of a comparable background of inorganic components, the lower Mesozoic reddish sediments of Site 546 and Hole 547B show significant differences, which are summarized in Table 4.

Site 546 sediments appear to be strongly influenced by the evaporitic environment. Chlorite is 25 to 30% more abundant than in the Hole 547B deposits, and its morphology seen by transmission electromicroscopy is exceptionally well shaped and often occurs as automorphous polygons (Plate 3, Figs. 4–6). Chlorite abundance roughly decreases above the halite deposits of Site 546. Regular mixed-layer clays occur as allevardite (illite–smectite) and later on as corrensite (chlorite–smectite), two minerals that are often associated with saline, restricted environments (Lucas, 1962). These minerals are characterized by automorphous forms, partly as laths for allevardite (?) (Plate 3, Figs. 1–3), and as well-shaped polygons for corrensite (Plate 2, Figs. 5, 6). The geochemistry at Site 546 points to the existence of a sodic character with a hypersaline environment passing into a common hemipelagic one: hypersodic (Core 546-20 to sample 546-18-2, 144 cm), sulphatic immediately above the salt (544-18-1, 110 cm to 546-17-4, 45 cm), magnesian (546-17-2, 130 cm to 546-17-2, 36 cm) and calcitic (546-17-1-50, 546-17-1, 18 cm). Such changes do not occur at Site 547, which is marked by a potassic character linked to the illite abundance, and which does not show the presence of saline evaporites above the continental crust. Microprobe investigations on $< 1\ \mu m$ particles of chlorite show a magnesian character at the base of both sites, with an increase of Fe content upward. However, the chlorite is more strongly enriched in Mg at Site 546 (Core 546-18) than at Site 547. To conclude, the reddish sediments of Hole 547B are probably the result of the fast erosion of emerged sialic rocks with

Table 2. Mineralogical and geochemical correlations between Site 547 and Site 545 black shales.

Site 547[a] Cores	Site 547[a] Data	Site 545 Data	Site 545 Cores		
51A-52A	0	—	29-31	P_2O_5(%)	General correlations
54A-55A	0.37	0.20	33		
57A-64A	0	0	34-37		
66A-73A	0.06	0.18	38-40		
+(5B-2B)	(0.16)				
51A-64A	11.32	10.01	29-37	Al_2O_3/K_2O	
66A-73A					
2B-5B	6.55	6.59	38-40		
51A-64A	3.20	2.97	29-37	Fe_2O_3/MgO	
66A-73A					
2B-5B	1.23	1.47	38-40		
60A-64A	↘	↘	37	Illite	Detailed correlations–Mineralogical trends
66A-73A					
2B-5B	↗	↗	37-40		
39A	↘	↘	29-31	Smectite	
60A-64A	↗	↗	37		
66A-73A					
2B-5B	↘	↘	37-40		
40A-59A	↗	↗	32-36	Kaolinite	
60A-64A	↗	↗	37		
66A-73A					
2B-5B	↘	↘	37-40		
39A	↗	↗	29-31	Palygorskite	
40A-59A	↘	↘	32-36		
60A-64A	↘	↘	37		
66A-73A					
2B-5B	↗	↗	37-40		

Note: ↗ relative augmentation of clay mineral abundance over time; ↘ relative diminution of clay mineral abundance over time.

[a] A & B indicate Holes 547A and 547B, respectively.

little subaerial weathering. On the other hand, Site 546 reddish sediments point to the existence of additional diagenetic processes marked by mineral growths in a restricted evaporite environment.

CONCLUSIONS

Mineralogical and geochemical analyses were performed on 115 samples from selected time slices of Leg 79 drill sites.

The Upper Cretaceous to lowest Tertiary claystones to marlstones recovered in Hole 547A are rich in smectite and also contain fibrous clays. These sediments mineralogically resemble the lower Paleocene deposits of the northeast Atlantic.

The upper Albian and Cenomanian redeposited green nannofossil claystones of Site 545 and Hole 547A contain similar clay and geochemical assemblages: high smectite contents, very low metalliferous accumulation, reduced environments, strong terrigenous influence, and high sedimentation rates. These assemblages suggest the existence of a hot climate with humidity-contrasted seasons along northwest Africa. Moderate but significant variations occur in the relative abundance of illite, smectite, kaolinite, palygorskite, P_2O_5, Al_2O_3, $K2_O$, Fe_2O_3, and MgO. The variations recorded are parallel in both DSDP sites. The trends observed in the inorganic stratigraphy support the biostratigraphical zonation in these series, which is marked by dissolution and resedimentation processes. Systematic lower content of smectite and higher contents of illite and kaolinite at Site 545 compared to Site 547 suggest the occurrence of differential settling processes, the former site being more proximal and the latter one more distal.

The upper Aptian to middle Albian green nannofossil claystones recovered at Site 545 are characterized by strong variations in the clay mineralogy and the inorganic geochemistry, especially as far as illite, smectite, palygorskite, MgO, K_2O, and P_2O_5 are concerned. These variations, recorded in an environment marked by reduced conditions, high sedimentation rates, and strong terrigenous influences, suggest an alternation of tectonically active and relaxed periods on the African margin, possibly in relation with the irregular spreading activity of the Mid-Atlantic Ridge.

The lower Mesozoic reddish claystones to mudstones of Site 546 and Hole 547B contain chiefly chlorite and smectite, associated with Li, and indicate strong physical erosion of high-relief sialic rocks. There is evidence of marked pedologic or post-depositional metamorphic processes. Unpublished studies show that the same results concern the barren grayish red sandy mudstones of Site 544. Site 546 halite and associated sediments, as well as the overlying pre-Miocene deposits, show higher chlorite contents, the local presence of regular mixed-layer clays (corrensite, allevardite), higher Na_2O/K_2O ratios, and upward geochemical sequences marked by successive dominances of Na, SO_4, Mg, and Ca parallel to a chlorite decrease. All these peculiarities point to the existence, at Site 546 only, of various early diagenetic processes in an alkaline, confined environment, from hypersaline conditions to hemipelagic ones.

ACKNOWLEDGMENTS

We are grateful to the U.S. National Science Foundation and to the Leg 79 Shipboard Party for giving us the opportunity to study sedimentary materials of Mazagan Plateau. The financial support of the study was given by CNRS (France) through Grant ATP GGO 1982. Technical and scientific assistance from M. Bocquet, J. Carpentier, F. Dujardin, E. Hanton, M. Leckie, A. Piqué, and P. Récourt are gratefully acknowledged.

REFERENCES

CEPM Laboratory, 1980. Results of X-ray mineralogy analyses of samples from Deep Sea Drilling Project Sites 415 and 416, Moroccan Basin. *In* Lancelot, Y., Winterer, E. L., et al., *Init. Repts. DSDP*, 50: Washington (U.S. Govt. Printing Office), 707-713.

Chamley, H., 1979. North Atlantic clay sedimentation and paleoenvironment since the late Jurassic. *In* Talwani, M., Hay, W., Ryan, W. B. F. (Eds.), *Deep Drilling Research Atlantic Ocean: Continental Margins and Paleoenvironment*. Am. Geophys. Union, Maurice Ewing Ser., 3:342-361.

Chamley, H., Giroud D'Argoud, G., and Robert, C., 1980. Clay mineralogy of Cretaceous and Cenozoic sediments off the Moroccan margin, Deep Sea Drilling Project Sites 415 and 416. *In* Lancelot, Y., Winterer E. L., et al., *Init. Repts. DSDP*, 50: Washington (U.S. Govt. Printing Office), 715-724.

Debrabant, P., and Foulon, J., 1979. Expression géochimique des variations du paléoenvironment depuis le Jurassique supérieur sur les marges nord-atlantiques. *Oceanol. Acta*, 2:469-476.

Gibbs, R. J., 1977. Clay mineral segregation in the marine environment. *J. Sed. Petrol.*, 47:237-243.

Lucas, J., 1962. *La Transformation des Minéraux Argileux dans la Sédimentation. Etudes Sur Les Argiles du Trias.* Mem. Serv. Geol. Als.-Lorr., 23.

Maillot, H., and Robert, C., 1980. Minéralogie et géochimie des sédiments crétacés et cénozoiques dans l'Océan Atlantique sud (marge africaine, dorsale médio-atlantique). *Bull. Soc. Geol. France*, 22: (7):777–788.

Mélières, F., 1978. X-ray mineralogy studies, DSDP Leg 41. *In* Lancelot, Y., Seibold, E., et al., *Init. Repts. DSDP*, 41: Washington (U.S. Govt. Printing Office), 1065–1086.

Millot, G., 1964. *Géologie des Argiles*: Paris (Masson).

Robillard, D., and Piqué, A., 1981. Epitétamorphisme du Permo-Trias dans le Moyen-Atlas septentrional (Maroc): mise en évidence et zonation régionale. *Rev. Geol. Dyn. Geogr. Phys.*, 23:301–308.

Whitehouse, V. G., Jeffrey, L. M., and Debrecht, J. D., 1960. Differential settling tendances of clay minerals in saline waters. *Clays Clay Min. (7th Nat. Conf.)*, 1958:1–80.

Date of Initial Receipt: March 1, 1983
Date of Acceptance: September 6, 1983

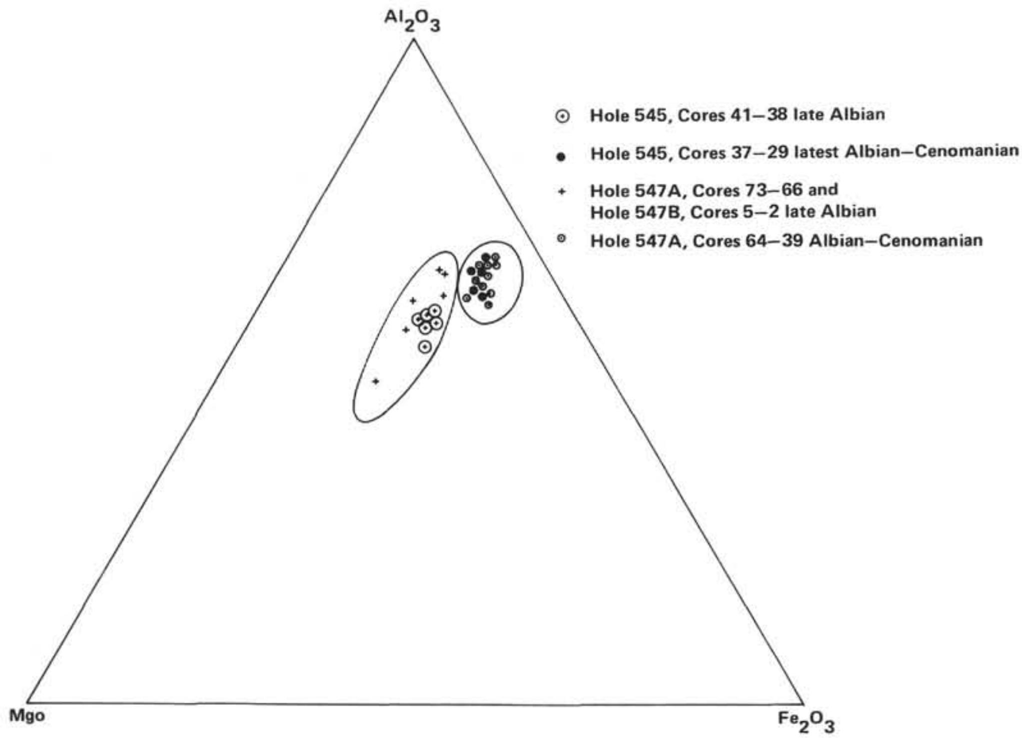

Figure 5. Geochemical identification of late Albian and latest Albian–Cenomanian time intervals, Sites 545 and 547.

Table 3. Geochemical analysis.

Sample	Major element oxides (%)									Trace elements (ppm)									
(interval in cm)	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2	P_2O_5	Sr	Mn	Zn	Li	Ni	Cr	Co	Cu	Pb	V
Site 545																			
29-2, 24-26	34.90	13.43	5.27	18.00	1.58	1.06	1.05	0.40	n.d.	615	342	116	36	38	95	15	10	17	140
31-1, 77-79	31.90	12.29	5.39	19.78	2.28	0.87	1.43	0.32	n.d.	489	473	110	36	53	104	18	10	28	100
33-1, 40-43	35.20	13.59	5.18	17.48	1.92	0.94	1.53	0.33	0.20	531	258	142	40	59	100	15	13	24	120
34-2, 70-71	40.00	16.45	6.28	11.50	1.69	1.18	1.70	0.39	n.d.	458	216	168	54	50	124	17	16	30	150
37-2, 40-42	39.30	14.76	6.68	12.62	2.43	1.18	1.46	0.40	n.d.	421	226	242	44	55	102	16	16	25	130
38-2, 100-101	12.20	3.86	1.63	36.86	2.36	0.52	0.70	0.10	0.41	899	137	163	10	56	62	12	19	36	70
38-3, 101-102	22.10	8.38	3.12	28.68	1.99	0.69	1.14	0.20	n.d.	657	174	163	25	44	77	12	18	26	90
39-2, 59-61	39.30	14.57	4.66	13.34	2.83	0.95	1.96	0.27	n.d.	421	231	184	49	39	95	9	15	24	130
40-1, 64-66	19.20	5.69	2.07	31.06	2.19	0.61	0.98	0.13	0.27	889	116	300	16	49	68	5	29	27	80
40-5, 58-60	29.30	9.39	3.05	22.84	3.01	0.82	1.37	0.17	0.24	526	163	379	24	41	63	11	99	26	170
41-3, 78-80	36.40	8.97	2.67	19.32	1.79	0.79	1.96	0.24	0.35	394	121	542	23	80	111	5	41	18	120
44-2, 14-18	32.90	8.69	2.90	22.61	1.97	0.77	1.90	0.18	n.d.	437	137	431	19	31	82	5	35	30	70
46-1, 75-77	28.10	8.02	2.67	25.93	1.85	0.65	1.72	0.18	n.d.	442	95	268	16	38	63	9	23	27	70
48-5, 75-77	36.50	9.70	3.17	19.92	2.40	0.82	2.05	0.21	n.d.	373	121	252	21	35	78	7	35	22	80
49-4, 8-10	25.90	5.41	1.75	29.60	1.61	0.56	1.30	0.13	n.d.	389	110	552	11	32	56	4	34	30	50
50-4, 57-59	21.30	4.72	1.94	32.54	1.51	0.55	1.17	0.13	n.d.	431	147	368	10	29	59	6	48	29	40
51-6, 28-30	22.70	5.39	2.11	30.97	1.50	0.59	1.33	0.16	n.d.	400	116	242	10	28	58	11	47	31	40
55,CC, 17-19	30.30	7.41	2.68	22.51	3.27	0.56	1.65	0.19	n.d.	237	126	663	15	35	60	9	25	28	70
56-6, 59-61	28.40	8.04	3.10	15.38	11.10	0.68	1.99	0.20	0.20	89	142	416	19	24	59	n.d.	27	24	60
Hole 547A																			
39-1, 42	13.00	6.22	2.97	36.57	1.03	0.46	0.66	0.27	n.d.	358	826	89	19	54	58	15	14	36	50
41-1, 13	44.00	18.32	7.26	7.40	1.69	1.33	1.21	0.50	n.d.	352	252	126	62	56	21	15	12	15	140
43-2, 64	35.70	13.95	6.45	15.24	2.12	1.07	1.24	0.19	n.d.	515	332	126	47	52	100	13	20	28	70
45-2, 18	38.80	15.36	6.07	12.67	1.81	1.31	1.21	0.27	n.d.	494	206	147	48	59	123	11	17	22	120
48-2, 50	39.50	15.65	6.78	11.35	1.70	1.36	1.10	0.45	n.d.	547	227	121	50	55	118	8	14	28	140
51-2, 50	37.80	15.90	6.25	12.81	1.96	1.35	1.61	0.38	n.d.	452	242	163	47	70	139	12	16	20	120
52-2, 50	33.30	14.85	5.90	15.70	1.75	1.17	1.34	0.21	n.d.	621	205	105	49	58	115	11	29	52	100
54-1, 30	39.10	17.16	6.71	10.32	1.87	1.29	1.66	0.31	0.46	515	242	116	57	51	124	15	17	19	140
55-2, 60	31.20	12.82	4.98	21.11	1.60	1.08	1.01	0.32	0.27	815	279	121	38	44	97	10	23	31	110
57-2, 50	36.00	13.65	5.34	17.71	2.06	1.13	1.39	0.32	n.d.	672	226	105	39	45	107	9	19	30	110
59-2, 50	41.00	15.39	6.18	12.77	1.84	1.47	1.34	0.28	n.d.	579	210	126	41	45	97	13	20	29	130
62-2, 50	37.10	14.52	6.12	14.11	2.25	1.34	1.50	0.40	n.d.	515	258	116	40	60	118	17	17	23	140
64-2, 50	33.50	12.38	5.19	18.34	2.45	1.08	1.30	0.36	n.d.	673	268	216	36	47	111	12	27	35	130
66-2, 136	15.80	5.99	2.73	31.54	2.42	0.58	0.91	0.16	n.d.	631	226	163	17	55	81	13	18	50	70
67-1, 100	18.10	6.75	2.65	31.18	2.03	0.72	0.92	0.19	n.d.	694	153	89	19	50	82	11	32	30	80
68-2, 115	27.20	9.66	3.70	22.78	3.10	0.82	1.57	0.20	n.d.	642	189	116	28	57	117	15	22	33	100
70-2, 50	29.00	10.41	4.21	21.43	3.42	0.85	1.74	0.21	n.d.	573	200	174	32	49	114	13	31	30	120
71-2, 50	32.40	10.22	3.82	19.45	3.56	0.92	1.62	0.22	n.d.	531	195	116	27	40	90	11	25	27	100
73-2, 50	38.50	13.68	5.20	12.51	3.31	1.13	2.17	0.24	n.d.	579	216	110	40	48	117	12	20	43	130
Site 546																			
17-1, 18	8.60	3.53	1.79	40.70	1.10	1.50	0.94	0.16	n.d.	205	1362	74	12	30	34	18	18	40	30
17-1, 50	13.70	4.81	2.40	36.45	1.48	2.03	1.34	0.21	n.d.	189	1036	79	14	31	32	17	21	40	40
17-2, 36	20.40	6.44	21.57	8.90	7.18	1.54	1.61	0.29	n.d.	431	7222	53	39	43	52	37	74	58	50
17-2, 50	49.20	11.19	6.81	4.92	7.45	2.68	2.11	0.51	n.d.	126	584	105	127	34	74	16	9	37	80
17-2, 130	44.60	14.64	7.13	3.86	7.12	3.24	3.01	0.61	n.d.	179	384	95	149	44	97	19	10	20	110
17-3, 4	20.90	8.17	4.21	25.88	1.38	3.04	2.13	0.35	n.d.	331	410	226	28	47	65	20	25	44	80
17-3, 89	44.40	14.29	4.71	2.60	8.28	4.88	3.65	0.56	n.d.	100	337	132	157	42	111	14	1	79	100
17-4, 45	11.70	4.62	1.75	27.95	2.48	0.96	0.85	0.19	n.d.	205	142	105	51	12	33	n.d.	6	69	40
18-1, 75	28.90	9.97	3.93	14.05	6.20	2.46	2.16	0.37	n.d.	159	247	137	121	27	52	3	21	46	80
18-1, 110	19.20	7.63	2.66	21.66	4.59	2.20	1.66	0.28	n.d.	210	205	195	86	23	47	5	13	54	60
Hole 548B																			
2-2, 50	34.80	12.11	4.72	17.89	2.61	1.07	1.77	0.23	0.18	646	221	116	37	58	113	10	21	23	110
4-3, 48	39.00	13.55	5.20	15.37	2.74	1.03	1.85	0.25	0.16	479	168	137	46	56	125	10	30	24	120
5-2, 50	42.00	14.36	5.56	11.19	3.61	1.28	2.35	0.28	0.22	400	231	137	48	69	143	12	22	24	130
25-3, 98	46.50	14.87	6.85	6.24	7.10	0.56	4.62	0.36	n.d.	89	610	74	117	65	87	15	n.d.	51	90
25-4, 91	47.60	17.31	4.92	6.02	4.89	0.60	4.58	0.40	n.d.	95	410	137	124	60	105	20	n.d.	35	110
26-2, 100	48.80	16.88	6.66	5.20	5.91	0.56	4.22	0.39	n.d.	110	416	100	122	50	90	13	n.d.	74	100
26-4, 60	44.40	14.58	4.31	6.87	7.55	0.60	3.69	0.33	n.d.	126	931	79	131	88	103	47	?	310	100
27-1, 2	48.70	18.77	7.15	3.84	5.14	0.54	4.40	0.44	n.d.	110	358	95	130	68	97	18	n.d.	26	120
27-3, 110	47.60	14.39	4.28	8.03	5.59	0.56	3.50	0.27	n.d.	747	500	68	122	83	128	14	21	90	90
28-4, 80	47.50	15.49	6.34	5.97	6.12	0.47	3.73	0.38	n.d.	126	521	95	121	67	101	18	n.d.	37	100
29-1, 110	41.60	15.53	5.42	10.98	5.01	0.64	3.48	0.38	0.15	163	494	89	110	50	86	13	104	48	100
30-3, 80	41.30	15.27	4.55	11.07	5.44	0.48	3.47	0.34	0.16	174	579	89	140	72	102	16	74	19	90
31-3, 90	44.00	14.77	5.66	9.35	4.71	0.54	3.74	0.33	n.d.	168	726	110	121	50	82	12	n.d.	15	100
33,CC, 21	48.50	16.01	6.65	6.59	4.16	0.51	4.38	0.37	n.d.	137	663	100	122	55	84	17	n.d.	35	100
34-2, 100	50.50	17.65	7.39	5.37	3.30	0.58	4.70	0.36	n.d.	137	794	216	115	58	76	16	n.d.	23	100

Note: n.d. = no data.

Table 4. Main mineralogical and geochemical differences between Holes 546 and 547B reddish sediments.

	Hole 546, Cores 17-21	Hole 547B, Cores 25-34
Chlorite/illite	2.3 > C/I > 0.5	0.5 > C/I > 0.3
Regular mixed-layer clays	Corrensite (17 = 3, 89 cm) Allevardite (18 = 3, 18 cm)	Absent
Halite	Abundant	Absent
Anhydrite	Present	Absent
Na_2O/K_2O (see also Fig. 7)	1.43 > Na/K > 1.08	0.14 ±0.02
Vertical evolution upward	Strong: Na-, SO_4-, Mg- and Ca-rich successive dominances Irregular and strong decrease of chlorite above the halite-rich deposits, parallel to the main geochemical changes	Weak: slight increase of chlorite

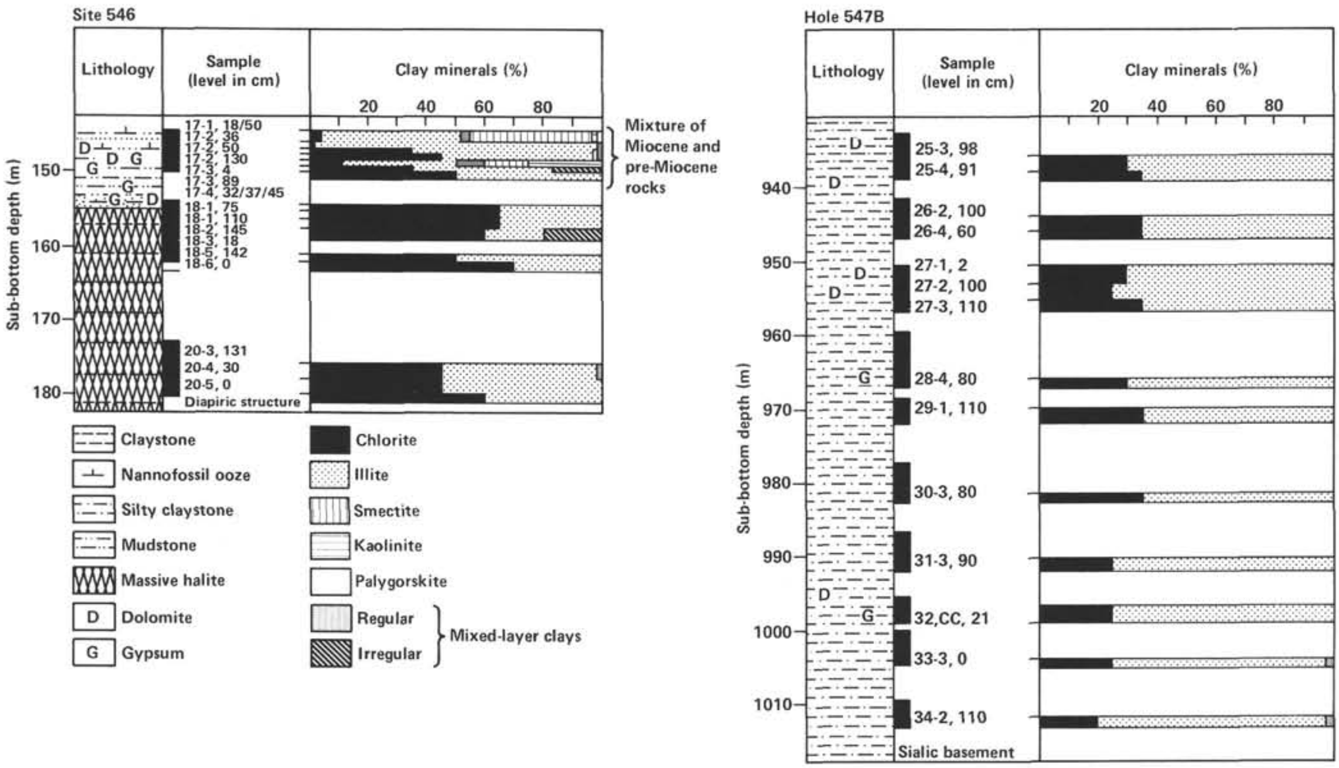

Figure 6. Early Mesozoic clay mineralogy, Sites 546 and 547.

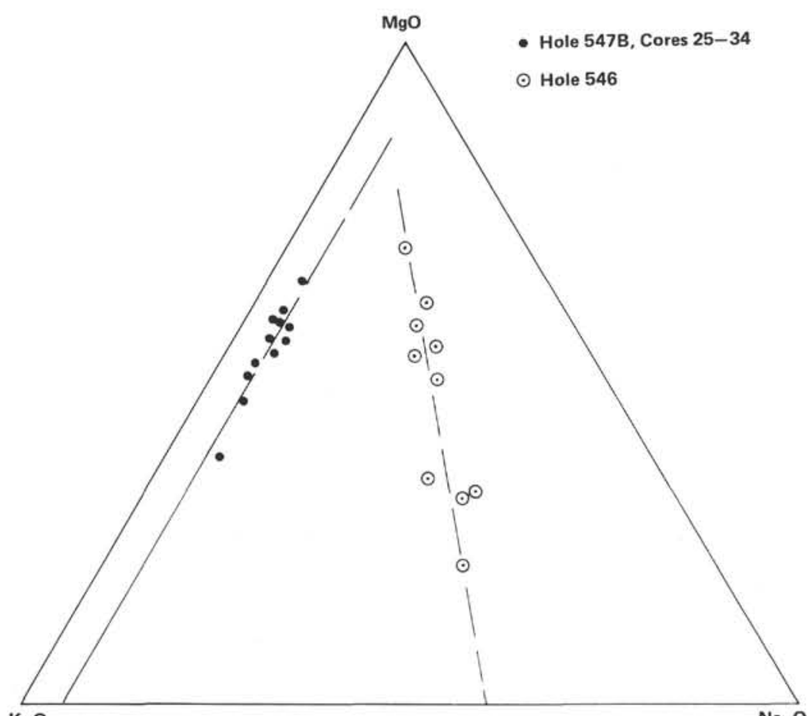

Figure 7. Geochemical data, Sites 546 and 547.

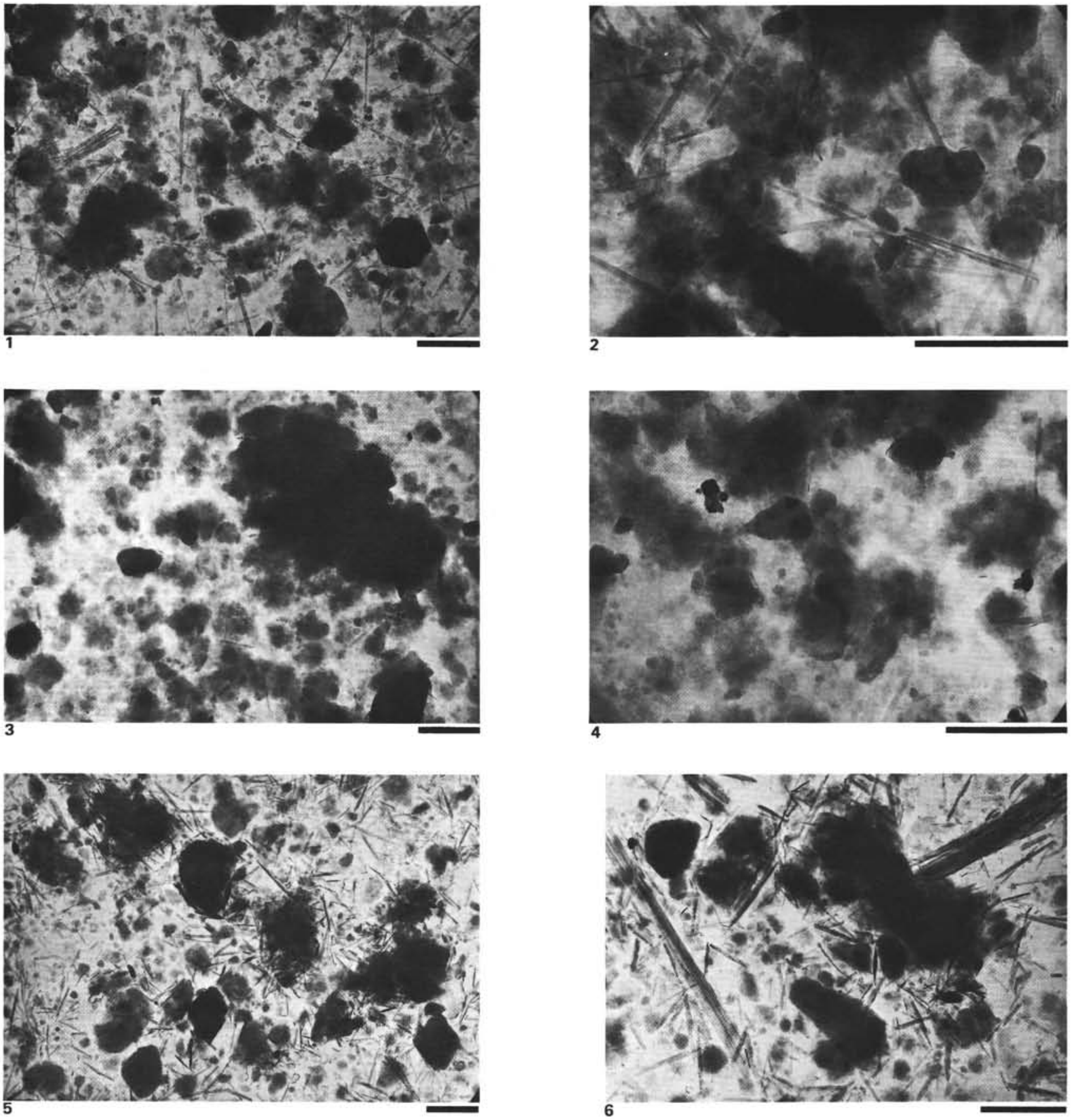

Plate 1. Electromicrographs. (Scale bar = 1 μm.) **1, 2.** Cenomanian, Sample 547A-39-1, 12 cm. Abundant smectite, common palygorskite broken fibers, some kaolinite hexagons. **3,4.** Cenomanian, Sample 547A-49-2, 50 cm. Very abundant smectite with blurred contours, rare kaolinite, and palygorskite. **5,6.** Aptian, Sample 545-48-5, 78 cm. Comparable amounts of illite, smectite and palygorskite. Many palygorskite fibers are still in compact bundles.

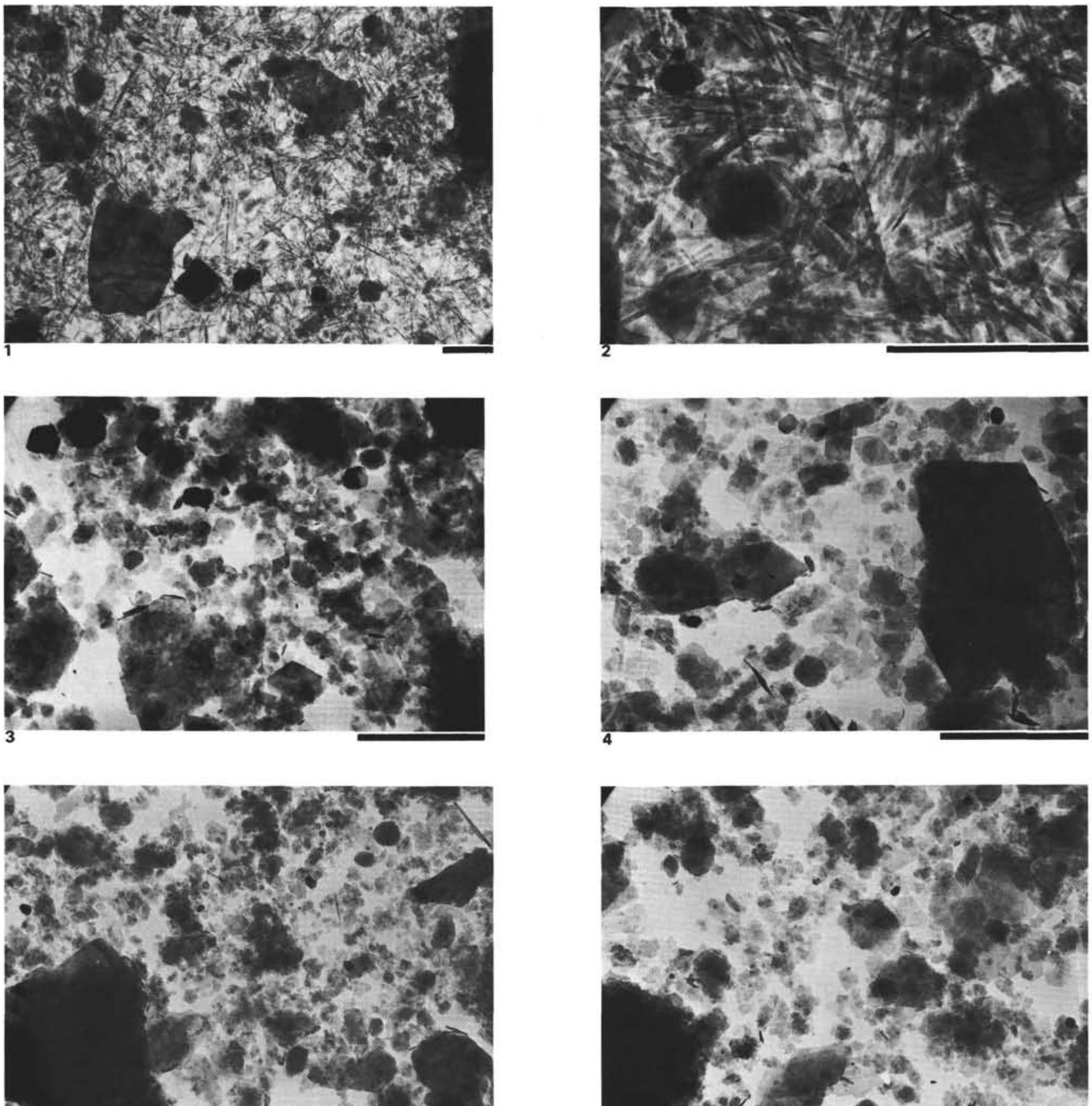

Plate 2. Electromicrographs. (Scale bar = 1 μm.) **1,2.** Aptian, Sample 545-55, CC 17 cm. Abundant palygorskite fibers, noticeable amounts of illite, smectite rare. **3,4.** Lower Mesozoic sediments deposited above a sialic basement, Sample 547B-27-2, 110 cm. Abundant illite, fairly abundant chlorite. **5,6.** Lower Mesozoic sediments above a halite body, Sample 546-17-3, 89 cm. Illite, chlorite, and corrensite, as well-shaped and polygonal sheets.

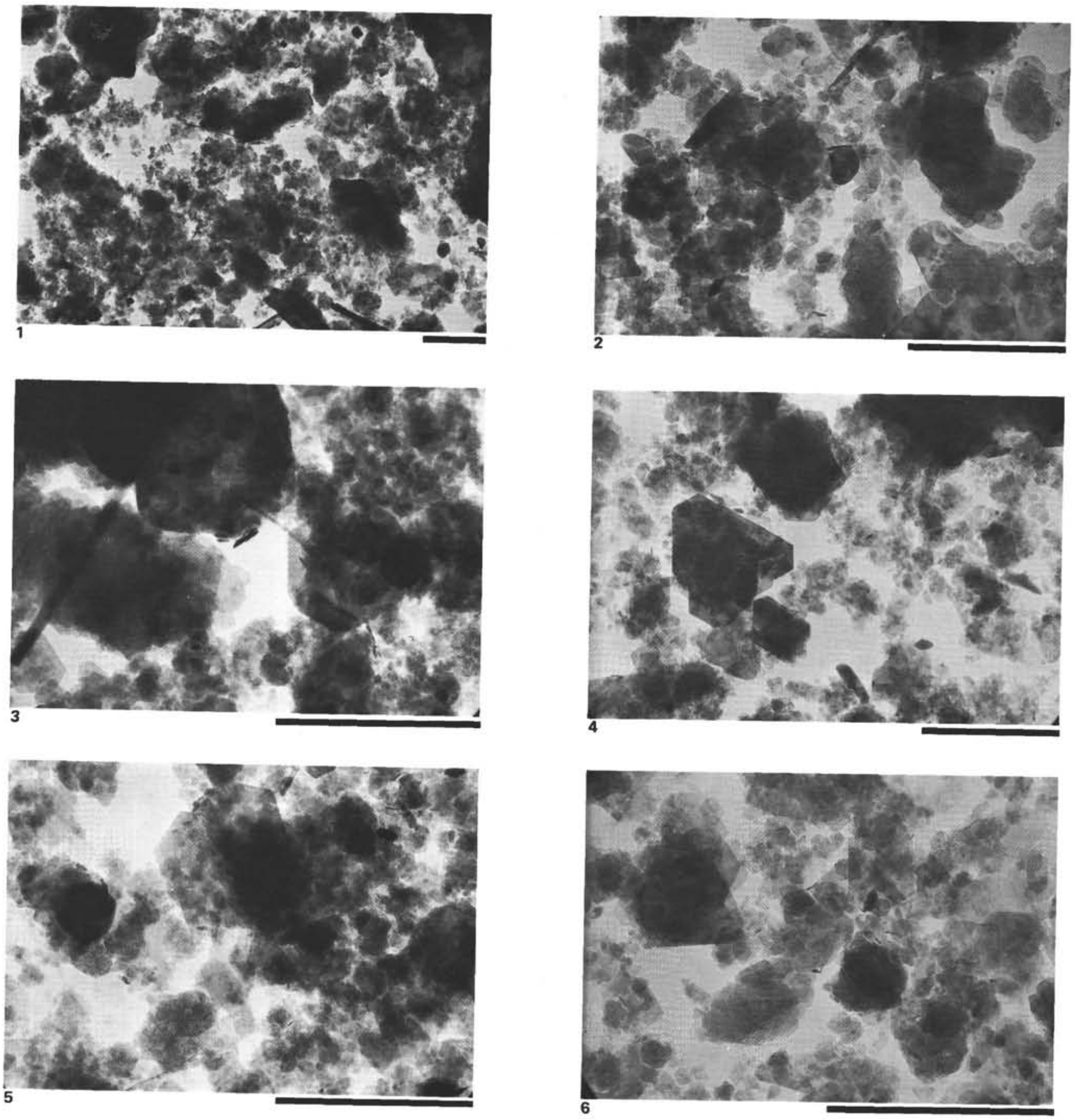

Plate 3. Electromicrographs. **1-3.** Early Mesozoic, reddish clayey level in a halite gypsum body, Sample 546-18-3, 8 cm. Very abundant chlorite polygonal phyllites, allewardite as broad and long laths (?), illite. **4-6.** Early Mesozoic, greenish clay in a halite body, Sample 546-20-4, 30 cm. Abundant chlorite and illite, well-shaped and polygonal phyllites.